Anticorrosive properties of Spiramycin for aluminum in acidic medium

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Abstract

Aluminum corrosion is a challenge in manufacture processes where this metal and its alloys are exposed to acid solutions. In the presence of a corrosion inhibitor, the damage to the aluminum surface is reduced significantly, meaning that the surface morphology is more protected due to the adsorption of inhibitor molecules onto the aluminum surface. Expired Spiramycin was investigated as a green corrosion inhibitor for pure aluminum in 0.1 M HCl solution at 293, 303, 313 and 323 K using the electrochemical method. Three concentrations (100, 150 and 200 ppm) of the drug were used. Corrosion testing showed good inhibition efficiencies (*IE*%) in 0.1 M HCl medium reaching 98.836% at an inhibitor concentration of 200 ppm and 293 K. The adsorption of Spiramycin on pure aluminum surface followed a Langmuir adsorption isotherm. Corrosion potentials revealed that Spiramycin acts as a mixed type inhibitor. Examination of the inhibited surface by SEM confirmed the adsorption of the drug molecules onto the aluminum surface. Furthermore, EDX analysis was performed. It can be observed that aluminum surface contains a percentage of carbon, hydrogen, and oxygen atoms from the adsorbed drug molecules. AFM indicated that the drug molecules contributed to the formation of a protective layer by adsorption on the aluminum surface. A FTIR spectral study showed that the protective deposit consisted of a metal–drug complex. The IR adsorption peaks were attributed to some functional groups of the inhibitor molecules adsorbed on the aluminum surface. Adsorption isotherm calculations indicated that the inhibitor underwent physical adsorption.

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1. Introduction

The reaction between the metal surface and its environment that degrades the properties of the material by chemical or electrochemical attack is called corrosion [1]. Studies on the mechanism of the corrosion of aluminum (Al) and its alloys continues to be of great interest due to their technological importance and industrial application, especially in household appliances, containers, electronic devices, cars and airplanes. Aluminum is noted for its relatively low metal density, softness, and non-magnetic properties [2, 3]. Inhibitory

substances are chemicals (natural or synthetic) added to the corrosive environment at low concentrations [4]. Inhibitors can be adsorbed on the metal surface by forming complexes between organic molecules that contain metal ions and a functional group or may participate in cathodic and anodic sites [5]. These inhibitors have extended π -electronic systems and functional groups (*e.g.* $-\text{C}=\text{C}-$, $-\text{OR}$, $-\text{NR}_2$, $-\text{OH}$, $-\text{NH}_2$ and $-\text{SR}$). Drugs are cheap, non-toxic, and have little negative environmental impacts, so they were suggested for replacing the traditional toxic corrosion inhibitors. The selection of some drugs as corrosion inhibitors is based on the following: (a) the drug molecules contain nitrogen, oxygen, and sulfur as active centers; (b) the drugs are reportedly environmentally friendly and also important in biological reactions; (c) drugs can be easily produced and purified [6]. Drugs retain at least 90% of their original potency even after the expiration date but their use for medical purposes is restricted due to professional limitations and liability concerns [7].

The use of expired drugs such as green corrosion inhibitors has attracted great attention due to their antibacterial and antifungal effects and the potential to reduce bio-corrosion. Most drugs are organic molecules that contain functional groups. The electronic density on the latter enhances the attraction of the inhibitor particles to metal surfaces through adsorption [8].

Previous studies dealt with the use of expired drugs as corrosion inhibitors for aluminum in acid media, including: antiemetic drug (meclizine hydrochloride) [9], antihypertensive drugs (Enalapril maleate, Atenolol, Etilefrine hydrochloride) [10], polyethylene glycol and Ciprofloxacin [11], Gentamicin, Kanamycin and Amikacin [12], Voltaren [13], Cefuroxime Axetil [14], Chloroquine [15], Cidamex [16], Caffeine [17], antibacterial drugs (penicillin, methicillin and nafcillin) [18], Theophylline Anhydrous [19], antibiotics drugs (Streptomycin and Tetracycline) [20], Cefixime [21], Alprazolam [22], Cefadroxil [23], Tramadol [24], Cefadroxil and Dicloxacillin [25], Nicotinamide [26], Antifebrin [27], Analgin [28], Naproxen [29], Sildenafil [30], and Suphtrim [31]. They have proven to be good inhibitors; these studies used polarization measurements of the inhibition process as well as thermodynamic, kinetic studies and adsorption isotherms.

This study aimed at the inhibition of the corrosion of pure aluminum by expired Spiramycin at various concentrations (100, 150 and 200 ppm) in 0.1 M hydrochloric acid at 20, 30, 40 and 50°C. Potentiostatic measurements and associated calculations confirmed the inhibitive effect of the investigated drug. The molecular structure of Spiramycin is given in Figure 1.

Figure 1. Schematic representation of Spiramycin structure.

2. Materials and Methods

2.1. Chemicals

Square shaped samples were cut from pure aluminum with the following chemical composition (%): Si 0.41, Fe 0.40, Cu 0.11, Mn 0.040, Mg 0.04, Cr 0.0, Zn 0.10, Ti 0.0 and Al 99.0. The samples were then grinded and polished using emery papers (600 to 3000) to obtain a flat surface. The polished samples were subsequently degreased with acetone and washed with distilled water. The 0.1 M HCl test solution was prepared by dilution of analytical grade stock (Merck) with water. Spiramycin was purchased from a medicine shop and three separate concentrations were added to the corrosive medium (100, 150 and 200 ppm) by dissolving the specified amounts of the inhibitor.

2.2. Active material tests

The active material in the drug was studied by high performance liquid chromatography (HPLC) to identify the recovery materials. The instrument was obtained from Japan, model: Shimadzu, LC2010A, column dimensions 25 cm×4.6 cm, 50% methanol/0.1 mM ammonium sulphate as a solvent, wavelength (λ) 210 nm, and flow rate 0.8 ml/min.

The extracted active material was studied for antibacterial efficiency using the well diffusion method. Gram positive *Staphylococcus aureus*, *Streptococcus epidermidis* and negative bacteria including *Escherichia coli*, *Klebsiella sp.* and *Candida albicans* were used. Suspension from the main culture was isolated with 4 mL of normal saline into a test tube, distributed on agar medium (Mueller Hinton), and left for 10 min to dry. Four wells (8 mm) were cut from the agar by a sterile cork borer, and 50 μ L of each concentration of the inhibitor (100–200 ppm) was added to the wells. The Petri plates were incubated for 24 h at 310 K to grow the bacteria. The diameter of the zone of inhibition was measured (in mm) and used as a measure of antibacterial activity.

2.3. Electrochemical measurements

A potentiostat/galvanostat M Lab 200 (Germany) was used to measure the electrochemical parameters with a three-electrode cell, using a Pt auxiliary electrode, a saturated calomel electrode (SCE) reference electrode; and the prepared steel specimens as the working electrode. All experiments were performed at 293, 303, 313 and 323 K using a water bath to control the temperature. The Tafel extrapolation method was used to measure the corrosion potential (E_{corr}), corrosion current density (i_{corr}), and Tafel slopes (b_c and b_a).

2.4. Inspections

The surfaces used for the inhibition studies were imaged using scanning electron microscopy (SEM), energy dispersive X-ray (EDX), and Fourier transform infrared (FTIR) spectroscopy of the film formed of the adsorbed drug using a KBr disc.

3. Results and Discussion

3.1. Tests for the active material in the drug sample

The recovery of active material from the expired Spiramycin was performed via HPLC, as illustrated in Figure 2. This figure indicates the presence of active materials in the big curve compared with the standard material in the small figure. This test confirmed that the active drug material was obtained.

Figure 2. HPLC analysis for the extracted active material from the drug compared with the standard material in the small figure.

The antibacterial activity of expired Spiramycin was studied using the well diffusion method and the results are shown in Figure 3. The inhibition zone against bacteria was measured in mm and the related results are listed in Table 1. The antibacterial properties of the expired Spiramycin induced cell death. Spiramycin has a good antibacterial activity against both gram positive and negative bacterial cultures.

Table 1. Data of antibacterial test.

Type of bacteria	Concentration of Spiramycin			
	0.2	0.4	0.6	0.8
<i>Staphylococcus aureus</i>	39	40	43	43
<i>Staphylococcus epidermidis</i>	39	42	44	45
<i>Escherichia coli</i>	23	25	25	26
<i>Klebsiella sp.</i>	20	22	23	25
<i>Candida albicans</i>	36	40	40	45

Figure 3. Antibacterial activities of Spiramycin compound against selected Gram-positive and Gram-negative bacteria and *Candida* using the well diffusion method.

3.2. Polarization behavior

Aluminum corrodes in hydrochloric acid to produce metal ions at the anode and hydrogen gas at the cathode. Spiramycin was added at three concentrations (100, 150 and 200 ppm) to 0.1 M HCl medium to reduce the corrosion of Al at four temperatures (293, 303, 313 and 323 K). Figure 4 shows the Tafel plots of inhibition under the experimental conditions indicating the cathodic and anodic regions.

The measured corrosion data are listed in Table 2 showing that the corrosion potentials (E_{corr}) shifted to more positive or more negative values compared with the uninhibited solution indicating that this inhibitor is of mixed type. At constant temperature, the corrosion current density (i_{corr}) values decreased after adding the inhibitor; *i.e.*, the inhibitor acted as the barrier to isolate the aluminum surface from the medium, indicating that the corrosion rate (CR) also decreased, as calculated using the following equation [32];

$$C_{\text{R mpy}} = 0.13 \cdot i_{\text{corr}} \cdot \frac{e}{\rho} \quad (1)$$

Tafel slopes (b_c and b_a) varied with concentration and temperature due to variation of the reactions at cathodic and anodic sites.

Figure 4. Tafel plots of inhibition by Spiramycin.

Table 2. Measured data of corrosion inhibition by Spiramycin.

Conc., ppm	Temp., K	$-E_{\text{corr}}$, mV	i_{corr} , $\mu\text{A}\cdot\text{cm}^{-2}$	$\text{mV}\cdot\text{dec}^{-1}$	
				$-b_c$	$+b_a$
Blank	293	664	147	195.4	69.2
	303	688	213	90.0	254.8
	313	751	240	119.3	88.8
	323	656.5	393.4	58	162.6

Conc., ppm	Temp., K	$-E_{\text{corr}}, \text{mV}$	$i_{\text{corr}}, \mu\text{A}\cdot\text{cm}^{-2}$	$-b_c$	$+b_a$
				$\text{mV}\cdot\text{dec}^{-1}$	
100	293	665	19	53.6	30.2
	303	718	29	51.7	55.0
	313	595	34	49.1	80.6
	323	694.3	68.7	301.5	16.7
150	293	635	11	72.0	16.5
	303	711	16.5	27.6	40.8
	313	735	21	34.5	37.4
	323	711	63.13	80.5	233.3
200	293	698	1.71	12.6	32.6
	303	687	7.37	54.9	28.3
	313	659	9.5	23.9	36.5
	323	663.1	43.34	39.6	29.6

The corrosion current densities before and after inhibition can be used to calculate inhibition efficiency percentage ($IE\%$) as follows:

$$IE\% = \left[1 - \frac{i_{\text{corr, inhibited}}}{i_{\text{corr, uninhibited}}} \right] \cdot 100 \quad (2)$$

Where $i_{\text{corr, inhibited}}$ and $i_{\text{corr, uninhibited}}$ denote the corrosion current density in the inhibited and uninhibited media, respectively. The $IE\%$ value listed in Table 3 indicates that 200 ppm of the expired drug is the optimum concentration at 323 K.

Other parameters can also be calculated such as the polarization resistance (R_p) and porosity percentage ($PP\%$) for the inhibition process using the following formula [32]:

$$R_p = \frac{b_c \cdot b_a}{2.303 \cdot i_{\text{corr}} (b_c + b_a)} \quad (3)$$

Where b_c and b_a are the cathodic and anodic Tafel slopes, respectively, and i_{corr} is the corrosion current density.

$$PP\% = \frac{R_{p, \text{uninhibited}}}{R_{p, \text{inhibited}}} 10^{\frac{-\Delta E}{b_a}} \cdot 100 \quad (4)$$

Where $R_{p, \text{uninhibited}}$ and $R_{p, \text{inhibited}}$ are the polarization resistances of the uninhibited and inhibited aluminum by the expired drugs, respectively, ΔE_{corr} is the corrosion potential difference between the two samples, and b_a is the anodic Tafel slope of the uninhibited

sample. The optimum concentration at 293 K exhibited the highest polarization resistance and lowest porosity of the adsorbed films.

It is clear that the inhibitor concentration of 200 ppm gave the highest resistance due to full coverage of the metal surface.

Table 3. Calculated data of corrosion inhibition by Spiramycin.

Conc. ppm	Temp., K	C_R , mpy	$R_p \cdot 10^3$, $\Omega \cdot \text{cm}^2$	IE%	PP%
Blank	293	63.693	0.150	—	—
	303	92.290	0.135	—	—
	313	103.989	0.092	—	—
	323	170.456	0.047	—	—
100	293	8.232	0.441	87.074	0.172
	303	12.565	0.399	86.384	1.748
	313	14.731	0.389	85.833	0.944
	323	29.767	0.100	82.536	0.585
150	293	4.766	0.529	92.517	0.716
	303	7.149	0.433	92.253	1.586
	313	9.099	0.371	91.250	0.491
	323	27.353	0.411	83.952	0.462
200	293	0.740	2.307	98.836	0.079
	303	3.193	1.100	96.539	2.051
	313	4.116	0.660	96.041	1.806
	323	18.778	0.169	88.983	0.910

3.3. Adsorption isotherm

Studies of the adsorption isotherm lead to know the type of adsorption, *i.e.*, whether it is physical or chemical, which depends on various parameters such as the organic inhibitor and the electrically charged metal surface. The most commonly used isotherm is the Langmuir isotherm given by the following equation:

$$\frac{C_{\text{inh}}}{\theta} = \frac{1}{K_{\text{ads}}} + C_{\text{inh}} \quad (5)$$

Where, K_{ads} is the equilibrium constant of the adsorption-desorption process, θ is the degree of surface coverage ($\theta = \text{IE}/100$) and C_{inh} is the inhibitor concentration in the solution bulk. The plots of C_{inh}/θ (ppm) against C_{inh} (ppm) for the drug at three temperatures are

straight lines (Figure 5) indicating that Spiramycin obeys the Langmuir isotherm. The linear regression coefficient (R^2) is close to unity.

Figure 5. Langmuir isotherm of Spiramycin adsorption on Al.

The apparent free energy of adsorption (ΔG_{ads}^0) is calculated from the relation:

$$\Delta G_{\text{ads}}^0 = -2.303RT \cdot \log(55.5K_{\text{ads}}) \quad (6)$$

Where: $K_{\text{ads}} = \theta / C(1 - \theta)$.

The negative values of ΔG_{ads}^0 indicate the spontaneous adsorption of the drug and reveal a physical interaction between the inhibitor molecules and the metal surface due to small values of free energy. Also, the values of K_{ads} are relatively small indicating that the interaction between the adsorbed drug molecules and Al surface is physical adsorption. The results are shown in Table 4.

The standard adsorption enthalpy change ΔH_{ads}^0 and the standard adsorption entropy change ΔS_{ads}^0 are correlated with standard Gibbs free energy through the relationship:

$$\Delta G_{\text{ads}}^0 = \Delta H_{\text{ads}}^0 - T\Delta S_{\text{ads}}^0 \quad (7)$$

ΔH_{ads}^0 and ΔS_{ads}^0 are obtained respectively as the intercept and the negative of the slope of the straight line obtained by plotting ΔG_{ads}^0 versus T (Figure 6). The change in adsorption enthalpy is negative, showing an exothermic process. The exothermic process means either physisorption or chemisorption. The change in standard adsorption entropy is positive, meaning that disorder increases during the adsorption process. This situation can be explained by desorption of water molecules replaced by the inhibitor.

Table 4. Data of adsorption by *Spiramycin*.

Conc., ppm	Temp., K	K_{ads}	ΔG_{ads}^0 , $\text{kJ}\cdot\text{mol}^{-1}$
100	293	0.067	−3.213
	303	0.063	−3.171
	313	0.060	−3.156
	323	0.047	−2.59
150	293	0.082	−3.704
	303	0.079	−3.736
	313	0.069	−3.514
	323	0.034	−1.773
200	293	0.424	−7.699
	303	0.139	−5.156
	313	0.121	−4.963
	323	0.040	−2.167

Figure 6. The relationship between the change in free energy and temperature.**Table 5.** Data of Spiramycin adsorption.

Conc., ppm	ΔH_{ads}^0 , $\text{kJ}\cdot\text{mol}^{-1}$	ΔS_{ads}^0 , $\text{kJ}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
100	−8.835	0.0188
150	−21.70	0.0602
200	−56.70	0.1679

To understand the effect of temperature on CR and $IE\%$ in the corrosion inhibition process, Tafel experiments have been performed in the temperature range between 293 and 323 K without and with different concentrations of Spiramycin in HCl solution. Plotting of $1/T$ (K) versus $\log(C_R)$ rate in each experiment was studied with the help of the Arrhenius equation, Figure 7. The apparent activation energy (E_a) can be calculated through the following equation [33]:

$$\log C_R = \log A - \frac{E_a}{2.303R} \cdot \frac{1}{T} \quad (8)$$

Where R is the gas constant ($8.314 \text{ J/K}\cdot\text{mol}$), A is the Arrhenius factor (slope) and T is the temperature of inhibited and uninhibited solution in Kelvin. The data listed in Table 6 show that the E_a values were generally higher in the presence of the drug as an inhibitor than in its absence. This indicates that adsorption decreases with increasing temperature and the adsorption of drug molecules occurs preferentially over H_2O molecules on the metal surface. Therefore, the optimum concentration (200 ppm) exhibited the highest activation energy.

Figure 7. Arrhenius diagram for aluminum in HCl with and without Spiramycin inhibitor.

Table 6. Activation energies of inhibited and uninhibited solution from 293 to 323 K of Spiramycin inhibitor in HCl.

C_{inh} , ppm	E_a , $\text{kJ}\cdot\text{mol}^{-1}$
Blank	24.10817
100	31.43769
150	42.77472
200	78.2448

3.4. Examination of the inhibited surface

The SEM photomicrographs of the surface of polished, corroded and inhibited aluminum samples in the presence of the most efficient concentration (200 ppm) of Spiramycin in HCl solution are shown in Figure 8. The polished surface of the sample appears to be smooth and displays no corrosion effects, as presented in the SEM image of the sample in Figure 8a,b, while the aluminum surface in the absence of Spiramycin inhibitor shown in Figure 8c,d displayed a few pits and cracks compared to the polished surface as a result to its exposure to corrosive solution. On the other hand, the surface of aluminum was covered by a film of the inhibitor molecules as seen in Figure 8e,f which is confirmed by increasing the thickness and roughness of the surface in AFM photomicrograph, also, the number of cracks and pits decreased clearly in the SEM image for the inhibited surface.

EDXs analysis was utilized to estimate the composition of the elements on uninhibited, corroded and inhibited surface of aluminum samples in HCl solution.

The EDXs spectra of the tested specimens are shown in Figure 9a–c. The percentage atomic content of aluminum on the polished, corroded and inhibited samples is 95.2%, 78.5% and 90.2%, respectively. It appeared from the EDXs analyses that the spectra of the corroded and inhibited coupons (Figure 9b,c) show a decrease in Al content compared to the spectrum of the polished sample (Figure 9a), which is due to the dissolution of aluminum atoms as a result of corrosion in the corrosive environment. In addition to that, the resulting spectrum of inhibited sample (Figure 9c) includes a peak corresponding to an element within Spiramycin (O) which indicates the adsorption of the inhibitor molecules on the surface of aluminum.

Furthermore, a decrease in Al content on the inhibited sample resulted from the formation of a protective layer on the aluminum surface. On the other hand, the EDXs spectra of the corroded sample showed a peak that corresponds to the Cl element resulting from the presence of the corrosive solution.

The FT–IR spectroscopy technique was utilized to identify the differences between the stretching vibrations of the functional groups in Spiramycin inhibitor and a film formed after adsorption of drug molecules on aluminum surface. Figure 10 illustrates the FT–IR spectra of Spiramycin inhibitor and the adsorbed film on the metal surface: the peak at 3485 cm^{-1} is attributed to O–H stretching vibration, and stretching of C–H aliphatic is at 2933 cm^{-1} . In addition to that, C=O stretching appears at 1722 cm^{-1} and C=C stretching aromatic is around 1675 cm^{-1} . C–N and C–O appear in the range from 1000 to 1350 cm^{-1} . The FT–IR spectrum of the inhibited layer obviously showed a decrease in the intensity of all stretching bands recorded in Spiramycin. According to the results obtained, it can be seen that the functional groups and active centers in Spiramycin inhibitor interacted with the Al surface and formed a protective film against corrosion, especially for the O–H group. This indicates that this group is attracted to the metal by adsorption to form an Al–drug complex.

Figure 8. SEM micrographs of aluminum surface (a,b) before immersion in 0.1 M HCl, (c,d) after corrosion in 0.1 M HCl, (e,f) after inhibition in 0.1 M HCl+200 ppm of the drug.

Figure 9. EDXs analyses of aluminum: a) polished specimen, b) corroded in HCl medium, c) samples inhibited by 200 ppm Spiramycin inhibitor.

Figure 10. FTIR spectra of Spiramycin (blue line) and film formed after adsorption on aluminum surface (red line, 200 ppm).

Atomic Force Microscopy (AFM) Characterization the Figure 11 shows the 2D and 3D images of the polished, corroded, and inhibited samples in the presence of 200 ppm of expired Spiramycin in the medium. These images show that the maximum peak-to-valley (in 3D images) was observed for the corroded sample (11.9 nm), while the minimum value occurred in the sample inhibited by 200 ppm of the drug (11.0 nm) due to the formation of a compact adsorbed inhibitor layer. The 4.6 nm peak-to-valley depth for the polished sample can be attributed to atmospheric corrosion. These data indicate that the aluminum surface immersed in the acid medium has a greater surface roughness than that of the polished metal, indicating that the unprotected aluminum surface is rougher and this is due to the corrosion of aluminum in HCl bulk. The average roughness values were calculated using AFM analysis, and the results are listed in Table 9.

Table 9. Data of AFM analysis.

Sample	Root-mean square height, nm	Maximum height, nm	Arithmetic mean height, nm	Developed interfacial area ratio, %
Polished sample	4.541	26.06	3.447	54.98
Corroded sample	5.871	33.09	4.717	161.5
Inhibited sample at 200 ppm	9.860	55.04	7.828	142.5

The results show that the average roughness of the polished aluminum surface is about 4.54 nm, while the roughness increased to 5.87 nm in the corroded sample as shown in

Figure 11c, d. On the other hand, the average roughness of the sample inhibited by 200 ppm of Spiramycin inhibitor molecules increased to 9.86 nm, and the increase in average roughness of the inhibited sample resulted from the of inhibitor molecules as cluster groups on aluminum surface [34].

Figure 12 shows the granularity cumulating distribution charts for the different samples, which show different distributions of particles with different average diameters on the aluminum surface.

Figure 11. 2D and 3D images of (a) polished, (b) corroded, (c) inhibited sample with 200 ppm of the drug.

Figure 12. Granularity accumulation distribution of particles for (a) polished, (b) corroded, (c) inhibited sample with 200 ppm of the drug.

4. Mechanism of inhibition

It is known that the efficiency of the inhibitor is affected by many factors including the chemical composition of the inhibitor through the abundance of electrons and the method of their distribution on the molecule in addition to the nature of the corrosive environment and the metal surface [35]. According to the data obtained from the adsorption study and based on the Gibbs free energy and enthalpy values, the type of adsorption that occurs between the Spiramycin molecules and the surface of the metal is of physical type.

The expired drug acts as a corrosion inhibitor for aluminum in 0.1 M HCl by adsorbing on anodic sites due to the hetero atoms in the drug structure (N and O atoms). In addition, the molecule contains high electron densities that strongly interact with the positive charge of Al ions at a pure aluminum/solution interface to form Al ion/drug complexes. These complexes act as a barrier to shield the metallic surface from the corrosive medium.

5. Conclusion

1. The evaluation of Tafel measurements for the inhibited solutions revealed that Spiramycin suppresses the dissolution of Al and acts as an anti-corrosive agent with an inhibition efficiency reaching 98.84% at 293 K and 200 ppm.
2. According to the polarization behavior of Spiramycin inhibitor, it can be classified as a mixed-type inhibitor.
3. Increasing the temperature of the inhibited solutions from 293 to 323 K led to a decrease in the inhibition efficiency of the inhibitor at each concentration.
4. The adsorption of Spiramycin inhibitor on aluminum surface obeys the Langmuir model at all the tested temperatures and the adsorption type was classified as physisorption.
5. The negative values of the $\Delta G_{\text{ads}}^{\circ}$ parameter for the inhibitor solutions indicate that the adsorption process between the inhibitor molecules and the metal surface is spontaneous.
6. The results of SEM–EDXs, AFM and FT–IR examination showed good evidence that a Spiramycin aluminum layer was formed.
7. The biological activity of Spiramycin against corrosive bacteria indicates that it has a good antibacterial activity against both gram-positive and negative bacterial cultures in addition to its corrosion efficiency.

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Conflict of Interest

The authors declare no conflict of interest.

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